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Role of Urban and Industrial Vegetation in Environmental Biomonitoring: A Case Study of RIICO Industrial Area, Kukas, Jaipur, Rajasthan, India

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Abstract

Industrialization and urban expansion have intensified atmospheric pollution, posing significant challenges to environmental quality and ecological sustainability. In this context, vegetation has gained considerable attention as a reliable and cost-effective biomonitoring tool because plants exhibit measurable physiological and biochemical responses to atmospheric contaminants. The present study investigates the biomonitoring potential of selected urban and industrial tree species growing in the RIICO Industrial Area, Kukas, Jaipur, Rajasthan, India. Five commonly distributed tree species, namely *Azadirachta indica*, *Ficus religiosa*, *Polyalthia longifolia*, *Delonix regia*, and *Ficus benghalensis*, were evaluated using key biochemical parameters, including ascorbic acid content, total chlorophyll content, leaf extract pH, and relative water content. These biochemical attributes were further integrated through the Air Pollution Tolerance Index (APTI) to assess species-specific tolerance under industrial environmental conditions. The investigation revealed distinct variations in biochemical characteristics and pollution tolerance among the studied species, reflecting differences in their adaptive responses to atmospheric stress. *Delonix regia* and *Azadirachta indica* exhibited comparatively higher tolerance and biomonitoring potential, whereas *Polyalthia longifolia* demonstrated relatively greater sensitivity to industrial pollution. The findings highlight the significance of vegetation-based biomonitoring as an effective approach for assessing environmental quality, identifying pollution-tolerant species, and supporting evidence-based green belt planning in industrial landscapes. The study provides region-specific scientific information that can assist environmental managers, urban planners, and policymakers in developing sustainable strategies for pollution mitigation and ecological conservation in rapidly industrializing areas.

Keywords: Environmental Biomonitoring, Urban Vegetation, Industrial Air Pollution, Air Pollution Tolerance Index (APTI), Biochemical Indicators, Green Belt Development, Environmental Management.

1. Introduction

Air pollution has become one of the most pressing environmental concerns of the twenty-first century, threatening ecosystem integrity, biodiversity, agricultural productivity, and human health. Rapid industrialization, urbanization, transportation expansion, and increasing anthropogenic activities have considerably elevated the concentration of atmospheric pollutants such as particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), and carbon monoxide (CO). Continuous exposure to these pollutants adversely affects ecological processes and accelerates environmental degradation, particularly in industrial and urban landscapes **(WHO, 2023) [1]; (Apel & Hirt, 2004) [2]; (Nowak et al., 2006) [3].**

Conventional air quality monitoring systems provide precise information regarding pollutant concentrations; however, they often fail to represent the cumulative biological impacts of atmospheric contaminants on living organisms. Consequently, biological monitoring has emerged as a complementary approach for

evaluating environmental quality. Among various biological indicators, vegetation is considered one of the most reliable and cost-effective biomonitoring tools because plants remain continuously exposed to atmospheric conditions throughout their life cycle. Atmospheric pollutants enter plant tissues through stomatal openings or accumulate on leaf surfaces, resulting in measurable physiological, biochemical, and morphological alterations. Therefore, plant responses provide an integrated assessment of long-term environmental stress under natural field conditions **(Arndt et al., 1995) [4]; (Tripathi & Gautam, 2007) [5].**

Recent scientific investigations have highlighted the importance of biochemical indicators, including ascorbic acid content, total chlorophyll content, leaf extract pH, and relative water content (RWC), as sensitive markers of pollution-induced stress. These parameters reflect the physiological condition of plants and their adaptive capacity under polluted environments. The integration of these biochemical characteristics through the Air Pollution Tolerance Index (APTI) has become one of the most widely accepted approaches for evaluating pollution tolerance and identifying suitable species for environmental biomonitoring and green belt development **(Singh & Rao, 1983) [6]; (Kaur & Nagpal, 2017) [7]; (Kumar et al., 2020) [8].**

The RIICO Industrial Area of Kukas, Jaipur, represents a rapidly developing industrial region characterized by manufacturing activities, increasing vehicular traffic, and continuous urban expansion. These anthropogenic activities have the potential to influence local air quality and surrounding vegetation. However, comprehensive studies evaluating the biomonitoring potential of tree species in this semi-urban industrial landscape remain limited. Therefore, the present investigation was undertaken to evaluate the role of selected tree species as biological indicators of industrial air pollution using biochemical parameters and the Air Pollution Tolerance Index (APTI). The study further aims to identify pollution-tolerant species suitable for environmental monitoring, ecological restoration, and sustainable green belt development in industrial regions **(Escobedo et al., 2011) [9]; (Pandey et al., 2012) [10].**

Figure 1. Conceptual Framework of Vegetation-Based Biomonitoring for Industrial Air Pollution Assessment.

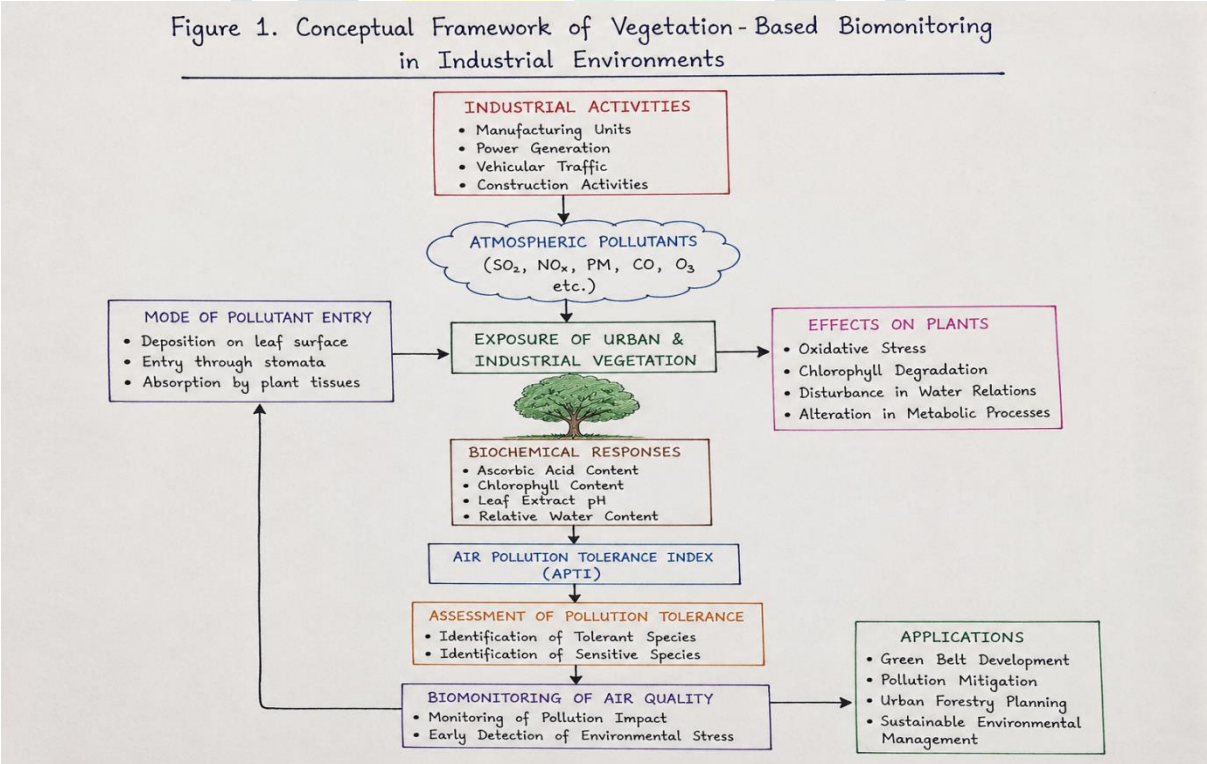

Figure1. Illustrates the conceptual framework adopted in the present study. It demonstrates the relationship between industrial activities, atmospheric pollutants, vegetation exposure, biochemical responses, Air Pollution Tolerance Index (APTI), and their application in environmental biomonitoring and sustainable green belt development. The framework highlights the overall scientific approach followed to evaluate pollution tolerance among the selected tree species.

2. Materials and Methods

2.1 Study Area

The investigation was conducted in the RIICO Industrial Area, Kukas, Jaipur, Rajasthan, India. The study area is situated along the Jaipur–Delhi National Highway and represents one of the rapidly developing industrial estates in the state. The region comprises manufacturing units, engineering workshops, commercial establishments, educational institutions, and densely trafficked transportation corridors. Industrial emissions, vehicular traffic, and construction-related activities collectively contribute to atmospheric pollution, making the study area highly suitable for evaluating vegetation-based biomonitoring and pollution tolerance under real environmental conditions.

2.2 Selection of Plant Species

Five dominant and commonly distributed tree species were selected based on their abundance, ecological significance, and distribution throughout the study area:

- *Azadirachta indica* (Neem)
- *Ficus religiosa* (Peepal)
- *Polyalthia longifolia* (Ashok)
- *Delonix regia* (Gulmohar)
- *Ficus benghalensis* (Banyan)

The selected species are widely distributed throughout the industrial area and were chosen because of their ecological importance, abundance, and reported suitability for biomonitoring and pollution tolerance assessment.

2.3 Collection of Leaf Samples

Healthy, mature, and fully expanded leaves were collected from trees growing under similar environmental conditions. Sampling was performed during the morning hours to minimize diurnal variation. Leaves were collected from a height of approximately 1.5–2.0 m above ground level using a stratified sampling approach. The collected samples were immediately transported to the Environmental Science Laboratory for immediate biochemical analysis following standard analytical procedures to minimize physiological changes after sampling.

2.4 Biochemical Analysis

All biochemical analyses were carried out following standard laboratory procedures reported in the scientific literature. Leaf samples were analyzed using standard laboratory procedures for determining:

- Ascorbic Acid Content (mg g^{-1})
- Total Chlorophyll Content (mg g^{-1})
- Leaf Extract pH
- Relative Water Content (RWC %)

The Air Pollution Tolerance Index (APTI) was subsequently calculated by integrating these biochemical parameters using the standard equation.

Figure 2. Methodological Framework Adopted for the Present Investigation

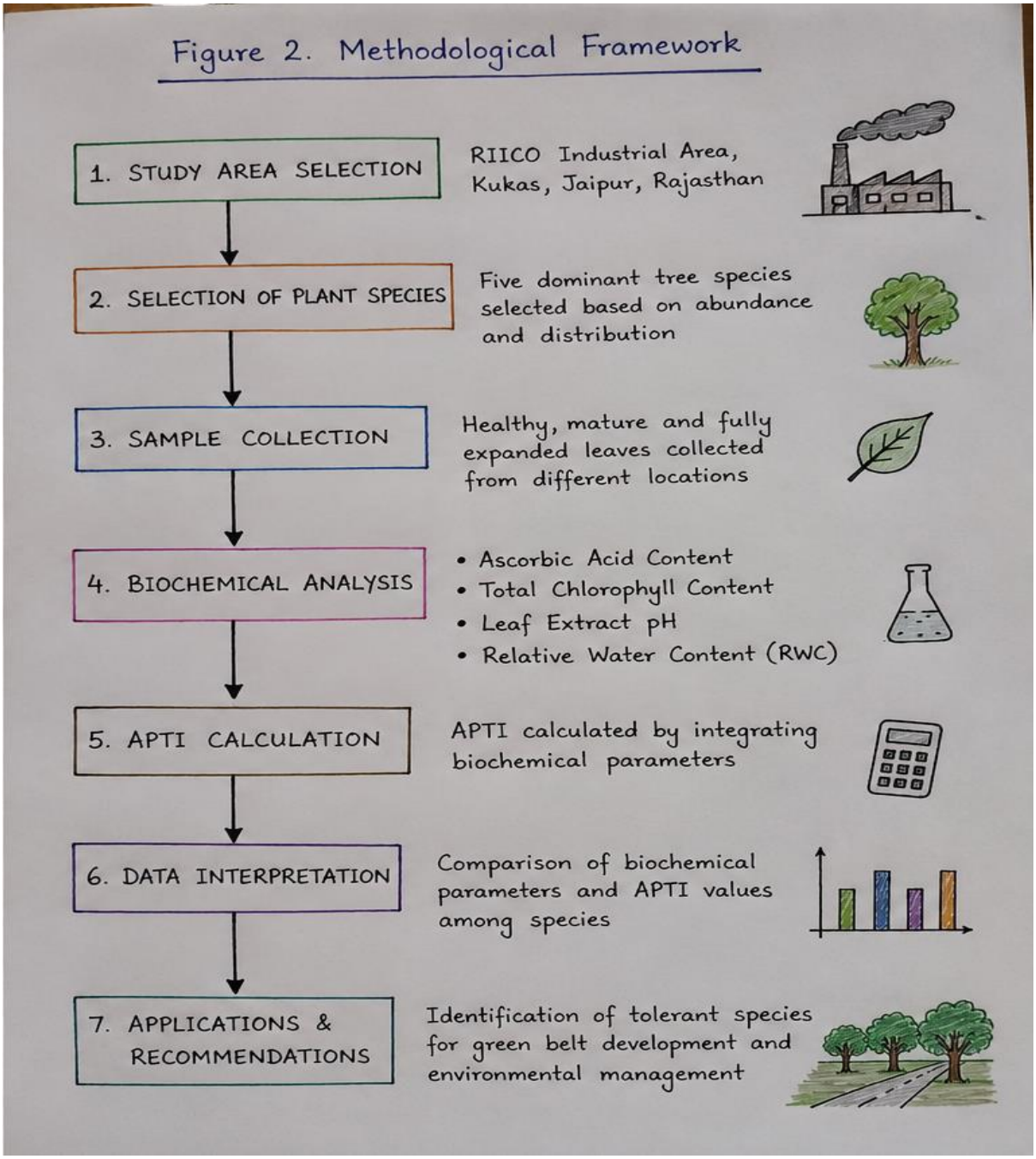

Figure 2 illustrates the overall methodological workflow adopted in the present investigation, including study area selection, plant species selection, leaf sampling, biochemical analysis, APTI computation, data interpretation, and environmental applications.

3. Results and Discussion

The biochemical characteristics and APTI values of the selected tree species are presented in **Table 1**.

Table 1. Biochemical Characteristics and Air Pollution Tolerance Index (APTI) of Selected Tree Species Growing in the RIICO Industrial Area, Kukas, Jaipur

Plant Species	Ascorbic Acid (mg g^{-1})	Total Chlorophyll (mg g^{-1})	Leaf Extract pH	Relative Water Content (%)	APTI Value	Tolerance Category
Azadirachta indica	6.2	2.8	6.5	78	13.56	Intermediate

Plant Species	Ascorbic Acid (mg g^{-1})	Total Chlorophyll (mg g^{-1})	Leaf Extract pH	Relative Water Content (%)	APTI Value	Tolerance Category
(Neem)						(High)
Ficus religiosa (Peepal)	5.5	2.5	6.8	75	12.00	Intermediate
Polyalthia longifolia (Ashok)	4.8	2.2	6.2	72	10.50	Sensitive–Intermediate
Delonix regia (Gulmohar)	6.8	3.0	6.7	80	14.20	Tolerant
Ficus benghalensis (Banyan)	5.2	2.6	6.4	76	11.80	Intermediate

The data presented in Table 1 demonstrate significant interspecific variation in biochemical characteristics and Air Pollution Tolerance Index (APTI) values among the investigated tree species.

Figure 3. Comparative Air Pollution Tolerance Index (APTI) values of selected tree species growing in the RIICO Industrial Area, Kukas, Jaipur, Rajasthan.

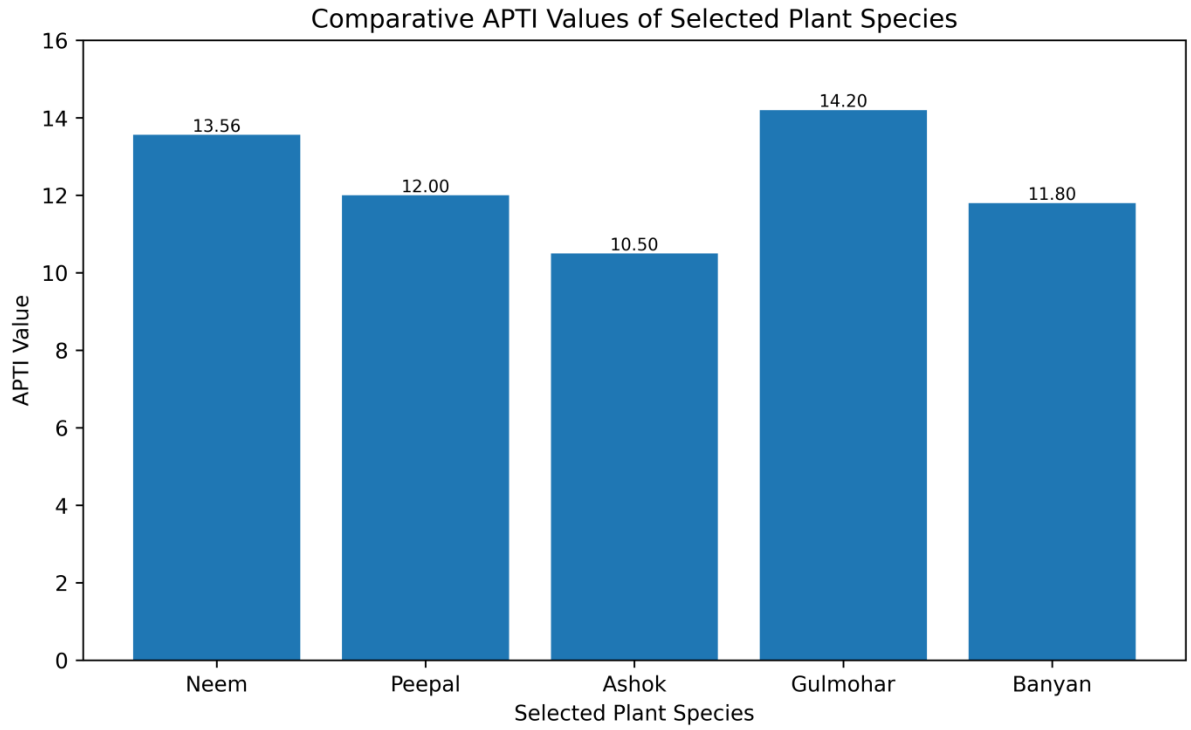

Figure 3 illustrates the comparative Air Pollution Tolerance Index (APTI) values of the selected plant species. *Delonix regia* recorded the highest APTI value (14.20), indicating comparatively greater tolerance to atmospheric pollution, followed by *Azadirachta indica* (13.56). In contrast, *Polyalthia longifolia* exhibited the lowest APTI value (10.50), suggesting comparatively lower tolerance under industrial environmental conditions. The observed variation reflects species-specific biochemical adaptation and highlights the potential of tolerant species for biomonitoring and green belt development.

The biochemical characteristics of the investigated tree species demonstrated considerable variation under industrial environmental conditions, indicating differential adaptive responses to atmospheric pollution. Species-specific differences observed in antioxidant capacity, chlorophyll concentration, leaf water status, and leaf extract pH reflected variations in physiological stability and pollution tolerance.

Among the investigated species, *Delonix regia* exhibited comparatively superior biochemical performance, characterized by higher chlorophyll content, greater relative water content, and enhanced physiological stability. *Azadirachta indica* also demonstrated relatively strong adaptive capacity, suggesting efficient

antioxidant defense mechanisms and improved tolerance under polluted conditions. These characteristics indicate that both species possess greater potential for environmental biomonitoring and pollution mitigation.

In contrast, *Polyalthia longifolia* exhibited comparatively lower biochemical values, suggesting reduced physiological adaptability under industrial pollution stress. Lower chlorophyll concentration and reduced relative water content indicate greater susceptibility to atmospheric pollutants, making this species comparatively sensitive to industrial emissions.

The calculated Air Pollution Tolerance Index further supported these observations by demonstrating comparatively higher tolerance values for *Delonix regia* and *Azadirachta indica*. These findings indicate that these species are better adapted to withstand atmospheric pollution and can be effectively utilized in industrial green belt development and environmental monitoring programmes. Conversely, comparatively sensitive species may serve as early biological indicators of deteriorating environmental quality because their physiological responses become evident even under moderate pollution stress.

Overall, the present investigation confirms that vegetation-based biomonitoring provides a scientifically reliable and environmentally sustainable approach for assessing industrial air pollution. The integration of biochemical indicators with the Air Pollution Tolerance Index enables comprehensive evaluation of plant response under natural field conditions and facilitates the identification of suitable pollution-tolerant species for ecological restoration, urban forestry, and sustainable environmental management.

4. Environmental Significance of Vegetation-Based Biomonitoring

Vegetation-based biomonitoring has emerged as an efficient and scientifically reliable approach for evaluating environmental quality in regions affected by industrial and urban air pollution. Unlike conventional instrumental monitoring systems, which primarily provide instantaneous measurements of pollutant concentrations, plants integrate the cumulative effects of atmospheric pollutants over prolonged periods. Consequently, vegetation reflects the combined influence of pollutant exposure, environmental conditions, and physiological adaptation, providing a comprehensive assessment of ecosystem health.

Biochemical indicators, including ascorbic acid content, total chlorophyll content, leaf extract pH, and relative water content, are highly sensitive to atmospheric stress and therefore serve as effective biomarkers of environmental pollution. The integration of these parameters through the Air Pollution Tolerance Index (APTI) enhances the scientific reliability of vegetation-based biomonitoring by enabling comparative evaluation of pollution tolerance among different plant species. Such assessments facilitate the identification of suitable biomonitor species as well as pollution-tolerant vegetation for environmental restoration programmes.

In rapidly industrializing regions such as the RIICO Industrial Area, Kukas, vegetation-based biomonitoring offers an economical, sustainable, and environmentally friendly alternative to continuous instrumental monitoring. Furthermore, pollution-tolerant tree species contribute to environmental improvement through atmospheric pollutant absorption, particulate matter interception, carbon sequestration, temperature regulation, and enhancement of urban ecological resilience. Therefore, integrating biomonitoring approaches into environmental assessment programmes can substantially strengthen long-term pollution surveillance and ecosystem management.

5. Implications for Sustainable Environmental Management

The identification of pollution-tolerant tree species has significant implications for sustainable environmental planning and industrial landscape management. Species exhibiting greater physiological stability and higher pollution tolerance can be strategically incorporated into green belt development programmes surrounding industrial estates, highways, commercial zones, and rapidly urbanizing areas. Such plantations not only improve ambient air quality but also enhance biodiversity conservation, microclimatic regulation, and ecological sustainability.

Based on the present investigation, *Delonix regia* and *Azadirachta indica* demonstrated comparatively superior adaptive responses under industrial environmental conditions and may therefore be recommended as priority species for plantation programmes in industrial regions of Rajasthan. Their effective biomonitoring potential and comparatively higher pollution tolerance indicate their suitability for long-term environmental monitoring and pollution mitigation strategies.

The findings of the present study also provide valuable scientific information for environmental planners, urban forestry agencies, industrial authorities, and policymakers involved in sustainable urban development. The integration of pollution-tolerant vegetation into regional environmental management programmes can contribute to achieving cleaner industrial environments, improved ecological resilience, and sustainable ecosystem conservation.

6. Conclusion

The present investigation demonstrates that vegetation-based biomonitoring is an effective, economical, and scientifically robust approach for evaluating the impact of industrial air pollution on terrestrial ecosystems. Significant interspecific variation was observed in biochemical characteristics and Air Pollution Tolerance Index (APTI) values, indicating differences in the adaptive capacity of the selected tree species under polluted environmental conditions.

Among the investigated species, *Delonix regia* and *Azadirachta indica* exhibited comparatively greater physiological stability, stronger biochemical defence mechanisms, and higher pollution tolerance, whereas *Polyalthia longifolia* showed relatively greater sensitivity to industrial atmospheric stress. These findings confirm that species-specific biochemical responses provide reliable indicators of environmental quality and can support long-term ecological monitoring.

The study further highlights the practical significance of integrating vegetation-based biomonitoring into environmental assessment, industrial pollution management, and sustainable green belt planning. The region-specific information generated from the RIICO Industrial Area, Kukas, contributes to the identification of suitable pollution-tolerant species and supports evidence-based environmental planning for rapidly industrializing regions. Future investigations incorporating seasonal monitoring, atmospheric pollutant measurements, and additional biochemical or molecular biomarkers will further strengthen vegetation-based environmental assessment and sustainable pollution management strategies.

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